UNIVERSITI TEKNIKAL MALAYSIA MELAKA

Faculty of Manufacturing Engineering

DEFORMATION OF L-SHAPED AEROSPACE COMPOSITE COMPONENTS

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DECLARATION

I declare that this thesis entitle “Deformation of L-Shaped Aerospace Composite Components” is the result of my own research except as cited in the references. The thesis has not been accepted for any degree and is not concurrently submitted in the candidature of any other degree.

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Date : ……………………………………

APPROVAL

I hereby declare that I have read this thesis and in my opinion this thesis is sufficient in terms of scope and quality for the award of Doctor of Philosophy.

Signature	:	…..……………………………….
Supervisor Name	:	…………………………………..
Date	:	…….……………………………….

DEDICATION

To my beloved parents, wife and family.

ABSTRACT

Advanced composite materials are increasingly selected to be used in fabricating new generation of aircraft primary structures than traditional materials due to its high strength-to-weight ratio, fatigue and corrosion resistance. Despite the rapid rising of the composite usage in aircraft industry recently, composite structures depict process-induced geometrical and dimensional distortion after processing. The shape deformation is unpredictable and contributes a mismatch between assembled components. Often, a traditional trial-and-error approach is deployed iteratively to ensure manufacturability in the mass production, which is very uneconomical, expensive and time consuming. There is still lacking experimental data and studies on the effect of different weaving styles of plain weave (PW), 5 harness satin (5HS) and 8 harness satin (8HS) in affecting shape deformation of angled composite laminates. The composite material selected was carbon fibre reinforced with epoxy matrix that could be cured at elevated temperature of 180°C with 7 bars pressure in the autoclave. Using design of experiment (DOE) methodology, two-level fractional factorials of 2^{4-1} Resolution IV were performed to investigate the main effects and interactions of different plies orientation, number of layers, sample sizes, tool materials as well as weaving styles in affecting the spring-in angle of composite laminates. From the design of experiments and analyses of variances, the plies orientation, number of layers, sample sizes and weaving styles were successfully determined to be significant when comparing the effect of PW and 8HS woven fabric. PW fabric induced approximately three times spring-in angle than 8HS. This relationship was determined to be strong with R-squared value of 97.2% and 87.9% when the aluminium and carbon tool was kept constant, respectively. Meanwhile, the relationship of PW and 5HS, and 5HS and 8HS were moderate with an average of R-squared values of 66%. There were some level two interaction terms affecting shape deformation mainly between plies orientation and tool materials when the weaving material was kept constant. On the other hand, the majority of level two interaction terms were between plies orientation and number of layers, and plies orientation and sample sizes when the tool materials were kept constant. Using the actual testing results of coefficient of thermal expansion and chemical shrinkage, the analytical data was calculated and compared with the actual measured results. The coefficient of thermal expansion and chemical shrinkage strain at the through-thickness direction is larger by 10 to 18 times than the in-plane properties dependent of the types of weaving pattern. Unfortunately, the analytical results were not in agreement with the experimental data possibly due to fibres misalignment and slippage during the lay-up process as well as non-thermoelastic properties not taken into account. Despite that, the effect of weaving styles cannot be ignored because statistically there were some main effects and interaction terms that might affect the shape deformation of L-shaped composite laminates.

ABSTRAK

Bahan komposit terkini semakin dipilih untuk digunakan dalam rekabentuk generasi baru struktur utama pesawat kapal terbang di bandingkan dengan bahan-bahan tradisional kerana mempunyai keutuhan bahan serta ringan, ketahanan struktur dan tiada pengaratan. Walaupun penggunaan komposit dalam industri pesawat meningkat baru-baru ini, struktur komposit mempunyai masalah kecacatan daripada segi geometri dan dimensi yang disebabkan oleh pemprosesan. Perubahan rupa bentuk tidak dapat diduga dan menyumbang kepada ketidaksepadanan antara komponen yang dipasang. Selalunya, teknik tradisional yakni percubaan berulang-kali digunakan untuk memastikan kesesuaian pengilangan sebelum pengeluaran besar-besaran, yang sangat tidak ekonomi, mahal dan memakan masa. Terdapat kekurangan data eksperimen dan kajian mengenai kesan gaya tenunan yang berbeza seperti tenunan biasa (PW), tenunan 5 satin (5HS) dan tenunan 8 satin (8HS) dalam mempengaruhi bentuk perubahan komposit laminat yang berbentuk sudut tepat. Menggunakan rekabentuk ujikaji dengan faktorial pecahan dua peringkat iaitu 2^{4-1} *Resolusi IV dilakukan untuk mengkaji kesan utama dan interaksi pelbagai lapisan orientasi, jumlah lapisan, saiz sampel, bahan acuan serta gaya tenunan dalam mempengaruhi perubahan komposit laminat. Bahan komposit yang dipilih adalah serat karbon yang diperkukuhkan dengan resin epoksi yang boleh dipanaskan pada suhu tinggi 180 ° C dengan tekanan 7 bar dalam mesin pendandang. Berdasarkan kepada rekabentuk eksperimen dan analisa variasi, didapati orientasi ply, bilangan lapisan, saiz sampel dan gaya tenunan adalah faktor-faktor yang signifikan di dalam mempengaruhi kesan tenunan PW dan 8HS. Tenunan PW boleh mengakibatkan perubahan sudut komposit laminat sebanyak tiga kali ganda besar berbanding dengan tenunan 8HS. Hubungan ini adalah kuat dengan mempunyai nilai* R^2 *sebanyak 97.2% dan 87.9% untuk setiap acuan yang diperbuat daripada aluminium dan karbon. Sementara itu, hubungan tenunan PW dan 5HS, dan 5HS dan 8HS adalah sederhana dengan nilai purata* R^2 *sebanyak 66%. Dari segi interaksi, hanya tahap dua dapat menjejaskan rekabentuk yakni di antara orientasi ply dan acuan apabila faktor tenunan adalah kekal. Sebaliknya, majoriti tahap dua dari segi interaksi adalah di antara orientasi ply dan jumlah lapisan, dan orientasi ply dan sampel saiz apabila faktor acuan adalah kekal. Daripada ujian makmal, keputusan kadar pengembangan haba dan pengecutan kimia resin digunakan untuk mengira analisa ramalan dan dibandingkan dengan keputusan eksperimen. Pekali pengembangan haba dan pengecutan kimia pada arah ketebalan lebih besar sebanyak 10 hingga 18 kali ganda daripada dalam-satah yang mana ianya bergantung kepada jenis corak tenunan. Malangnya, keputusan analisa ramalan dan eksprimen tidak sama berkemungkinan disebabkan oleh serat gentian tidak selari dan tergelincir, serta pengaruh bukan termoelastik yang tidak diambil kira. Walaupun begitu, kesan gaya tenunan tidak boleh diabaikan kerana secara statistik terdapat beberapa faktor-faktor utama dan interaksi yang mungkin dapat memberi kesan kepada perubahan rekabentuk komposit laminat berbentuk 'L'.*

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LIST OF ABBREVIATIONS AND SYMBOLS

ACT	Advanced Composite Tool
AITM	Airbus Industries Testing Method
ASTM	American Standard Testing Method
ANOVA	Analysis of variance approach
BMC	Bulk-moulding compound
CMC	Ceramic Matrix Composite
ΔT	Change in temperature
CS	Chemical shrinkage
CTE	Coefficient of thermal expansion
CTRM	Composites Technology Research Malaysia
CMM	Coordinated Measuring Machine
$\Delta\theta_{CS}$	Cure shrinkage
DOF	Degree of freedom
DOE	Design of experiment
DDM	Direct Differentiation Method
DMA	Dynamic Mechanical Analyser
8HS	Eight harness satin
E_f	Elastic modulus fibre
E_m	Elastic modulus matrix